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HAZARDS OF THE TROLLEY-LOCOMOTIVE HAULAGE SYSTEM IN COAL MINES

BY

D. HARRINGTON AND R. G. WARNCKE

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By D. Harrington[2] and R. G. Warncke[3]

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INTRODUCTION

The greatly extended use of the underground trolley-locomotive system for hauling coal without doubt was one of the most important factors in the rapid progress of coal mining and the increased production of coal in American coal mines during the period 1910-20. Much of the superior efficiency of production of our underground coal and metal mines should also be credited to the trolley locomotive system. The trend to mechanization of mines during the past 15 years, more particularly the past 5 years, with higher production per man employed and greatly accelerated advancement of working places, has required increased use of trolley locomotives, necessitating larger equipment, higher speeds, and more frequent turn over of pit cars. This is reflected in increased size of locomotives and the use of larger mine cars (some with a capacity up to or over 10 tons); moreover, heavier rails and larger-size trolley wires have been or ought to have been installed. Trolley-locomotive haulage has proved to be rapid, economical, efficient, and productive; nevertheless, in spite of these advantages, so many hazardous features and unsafe conditions are involved and the price paid in life and property is so high as to justify the statement that the system should be scrapped if it cannot be operated under reasonably safe conditions.

Since bare trolley wires were introduced into underground mines, they have been responsible for the death of hundreds of miners, property damage totaling millions of dollars, an indeterminate loss of tonnage through the abandonment of mines or parts of mines, and loss of time after disasters caused by fires or explosions originated by the trolley haulage system.

The heavy loss of life in some coal-mine fires in 1943 and 1944 that were caused by bare trolley wires has focused attention on the hazardous features of this system of transportation in coal mines. Many safety-conscious mining people have known these hazards for years, but operating executives have given them little, if any, consideration. Even progressive, safety-minded companies that use only permissible mining equipment at the face, permissible explosives for blasting, and permissible cap lamps for illumination and are careful to exclude such other sources of ignition as underground smoking and the indiscriminate use of welding machines, give little or no consideration to haulage operations as possible sources of ignition of gas or dust or causes of mine fires. Open-type trolley locomotives, receiving their power through bare trolley wires and causing arcs and sparks almost every foot of the trolley line when the haulage locomotive passes, operate not only in partial return-air currents from old, abandoned, partly pillared areas and active workings but also on full split returns or on main returns in mines giving off hundreds of thousands of cubic feet of methane a day. In hundreds of mines the bare trolley wire runs past abandoned territory filled with explosive gas held in place by relatively flimsy or leaky stoppings. About the only restriction is that in some regions the trolley wire must not be extended beyond the last open crosscut, but even then there seems to be no fear about extending trolley lines past open working rooms or other workings known to be liberating gas freely.

This paper proposes to point out and discuss some hazards of the bare trolley wire and the imminent, constant, universal danger of contact, gas- or dust-ignition, and fire hazards along every foot of bare wire from the mouth of the mine to the farthest recess of the workings to which it extends. Suggestions for their elimination will be given.

TROLLEY-WIRE HAZARDS

The hazards of the trolley-locomotive system are so numerous and so varied as almost to justify the word innumerable. They are present in every part of the system - in locomotives and their component parts; in the rails on which locomotives travel; in the hangers that support the trolley wires; and in every inch of the trolley wires. All of these have caused accidents and either directly or indirectly disasters. Little, if anything, can be done to prevent or even to materially decrease the hazards as long as this system of transportation is used underground; these hazards are intensified in coal mines.

Precautions in installing and maintaining trolley wires, precautions in operating locomotives, use of well-placed cut-out switches and circuit breakers, sectionalizing the circuits, and perhaps other precautions will minimize to some extent the danger of fire or explosion disasters; but neither these nor any other known precautionary measures can eliminate these hazards. Little can be done to prevent the sparking or arcing of the trolley wheel or harp with the trolley wire, locomotive wheels, and open-type controllers and motors - all possible ignition hazards. It is out of the question to predict with any reasonable degree of accuracy where or when, in the thousands of miles of trolley-haulage roads, a fall of roof or timber will bring down a trolley wire. It is equally impossible to predict when or where a trip of cars may be wrecked or derailed bringing down the trolley wire, and causing wrecked cars to touch it. Some of these may be preventable, but many circumstances can intervene to alter conditions - a broken rail, broken car wheel, breaking of a coupling or a link - all of which are impossible to forsee. Regardless of circumstances or conditions, the trolley wire can always cause trouble under any unforseen condition.

Trolley-circuit protective equipment, such as circuit breakers, operated automatically or manually offer at least some protection against short circuits by interrupting the electric current. However, the records of scores of fires, including disasters with multiple loss of life resulting from failure of circuit breakers to function when partial or direct short circuits occur, prove that these devices are by no means effective, and relatively little dependence should be placed on their acting promptly or effectively to avert mine fires or lethal shocks.

The relatively recent heavy increase in the several types of equipment in mechanical mining that use direct-current power from the very convenient trolley wire has greatly augmented the carrying requirements and ultimately the capacities of these circuits. Sometimes heavier trolley wire is used, and circuit breakers are set so high that partial short circuits fail to open them. Under these conditions a fall of roof bringing the trolley wire in contact with a loaded car of coal, close to or even touching the rail, can (and often does) cause an arc that ignites the coal, wood ties, or other combustibles without causing the circuit breaker to act. The arc may also ignite coal dust in suspension, initiating a dust explosion. A trolley-circuit protective device has not been developed that will assure interruption of power when partial contacts are formed through which low-density current is flowing. However, this does not mean that individual pieces of equipment cannot be protected. Heavy haulage units may draw 1,000 or more amperes; and with circuit breakers set above this load, a load of 50 to 100 amperes caused by a trolley wire touching a car or rail is not sufficient to trip the circuit breaker.

Some of the outstanding hazards that are known to exist in the trolley-locomotive system are given above; numerous others could be cited but they come into effect only occasionally and are unpredictable and therefore difficult to control even though known precautions are taken.

The trolley system in mines generally consists of the main or primary haulage and the gathering or secondary haulage. In some of the larger mines the secondary haulage might be divided further into gathering and relaying. Although primary and secondary haulage work as a unit each employs separate and to some extent different types of equipment. Primary haulage uses heavy locomotives (generally 10 to 15 or more tons in weight), heavier rails, wooden ties, and relatively heavy trolley wires; it is generally, but not always operated in fresh intake air. Secondary haulage has smaller equipment - in some places trolley-type, in others cable-reel, and in still others combination trolley-cable-reel locomotives are used. Such locomotives range from 5 to 8 tons, travel over lighter rails, and enter working sections near the face of the rooms. Some mines use storage-battery locomotives for gathering, and a very few have storage-battery locomotives for both gathering and main haulage. Since the introduction of mechanical loading, with its increased tonnage, it usually has been necessary for locomotives to travel closer to the face regions than in hand loading.

Division of the haulage system into the primary and secondary phases is emphasized further when the types and frequency of accidents, including ignitions of gas or dust or both are studied. This division of the system is also utilized when other coal-transportation methods are being considered due to changes brought about by mechanization at or near the faces.

Main-line haulage systems, with their heavier equipment are generally better installed and maintained than gathering systems. The main haulageways usually last the life of the mine or of sections comprising relatively large areas. Hence there is better roof support, and the roof itself is made higher, with trolley wires farther above the rail and better alined; in fact, the primary haulage is usually planned and maintained as a permanent installation. On the other hand, secondary trolley haulage is usually installed with little expenditure as to grading for height, or alinement or clearance; track rails are relatively small; bonding is not done thoroughly; and bonds and trolley supports are maintained anything but systematically.

The hazard of touching bare trolley wires usually is not as great in the main haulage as in secondary or gathering haulage; not only are bare wires usually higher above the rail in the main haulage, but also the frequency of exposure is much greater in the secondary haulageways. In secondary haulage bare trolley wire extends relatively close to the face regions where the mine workers must frequently pass or work under it, in many phases of their work. Gas-ignition hazards are much greater in secondary than in primary haulage because the former usually extends fairly close to or into the face region and working sections where gas is apt to accumulate along the haulageways and in adjacent rooms, sudden outbursts of gas from falls or caving in the advancing rooms or in pillar sections are liable to occur,, and interruption of the ventilating current is more likely to cause maximum accumulations of explosive gas. Falls of roof are more frequent in the gathering sections, and the breaking or bringing down the trolley wire results in fires or in ignitions if gas or dust is present. Derailments of cars and wrecks involving locomotives, cars, or trips occur more frequently in secondary haulage, always with the probability that trolley wires will be pulled down, with the ever-present possibility of fire, or explosion, or contact fatality, when that occurs.

Although accidents and disasters are more frequent in secondary haulage, the severity is likely to be greater in primary haulage, as illustrated in some of the following examples. Fires in the main haulage are difficult to control and are likely to spread rapidly due to the large volume of air traveling in the main entries, carrying the fumes and products of combustion to all sections of the mine if the haulage is on the intake or filling the escapeway with smoke and gas if the main haulage is on the return. The same hazards also apply to dust explosions in the main haulage and unless the haulage roads are adequately rock-dusted, explosions are likely to be propagated by dust throughout the mine.

ACCIDENTS RESULTING FROM THE TROLLEY-LOCOMOTIVE SYSTEM

The accidents resulting from the trolley-locomotive system can be divided into three classes: (1) contact of persons with bare wire or charged locomotive; (2) ignition of gas or dust; and (3) fires. Each of these classes might be divided further into the parts of the system responsible for the accident, explosion, or fire. The following are some of the numerous ways accidents have occurred from the trolley-locomotive system:

1. Contact of persons with bare trolley wire.

2. Contact of bare trolley wire with mine doors, timbering, roof, ribs, and curtains (fire hazard).

3. Arcs or sparks from poor or broken bonding, bad joints, or broken rails igniting coal or gas or timber ties.

4. Arcs or sparks from trolley wheel, harp, or shoe igniting combustible material, such as brattice cloth, wood, gas, or dust.

5. Arcs or sparks from locomotive controller or motor igniting gas or dust.

6. Arcs or sparks from locomotive wheels on poorly bonded track.

7. Falls of roof bringing down trolley wire and touching cars or rail, igniting coal or gas.

8. Wrecked or derailed cars causing coal dust to be thrown into suspension and ignited by arcs from the fallen trolley wire.

9. Explosions of Cardox shells, explosives, etc., through short circuits on trolley haulage trips or cars.

10. Stray currents from poorly installed trolley system causing premature detonation of electrically fired explosives.

Contact of Persons

Fatalities attributed to electrical causes comprise 4 to 5 percent of the total fatalities in coal mines. The bare trolley wire and the locomotive were responsible for 60 to 70 percent of all electrocutions underground from 1930 to 1942 and for approximately one third of all lost-time accidents caused by electricity. Table 1 shows both fatal and nonfatal accidents from the locomotive trolley system compared to those caused by all electrical causes.

A study of this table reveals that, although the number of fatalities from electrical causes fluctuated during these years and there is a slight tendency toward reduction of electrical contact accidents in the coal mines of the United States, the percentage of deaths from trolley wire remained nearly constant.

This tabulation, however, does not include all fatalities in the coal mines of the United States due to electrical contacts in the coal mines of the United States. Every year there are several fatalities on trolley haulage roads in which the victim touches the trolley wire while sitting in the locomotive cab, while helping to rerail a derailed car, while coupling or uncoupling cars, or while getting off or on a locomotive or a car trip and is thrown under the moving locomotive or cars or between the locomotives or cars and a timber or the rib and killed. His accident is then charged to haulage rather than electricity, although the fundamental cause of the accident was the electrical shock that threw the victim into a position to be killed by the haulage agency. Every year several men are killed on trolley haulage roads when a motorman becomes shocked while handling the trolley pole or otherwise and the locomotive gets out of control, knocking out one or more timbers and letting down the roof. The resultant fatalities are charged to falls of roof rather than electric shock from the trolley system.

TABLE 1. - Electrical contact accidents in coal mines, 1929-42

Year	Bituminous				Anthracite			
	Fatalities		Nonfatalities		Fatalities		Nonfatalities	
	Trolley wires and locomotives	All elec. causes	Trolley wires and locomotives	All elec. causes	Trolley wires and locomotives	All elec. causes	Trolley wires and locomotives	All elec. causes
1930...	42	63	467	1,237	5	8	126	336
1931...	41	62	311	910		3	78	253
1932...	31	42	238	651	3	5	59	202
1933...	32	46	246	652	5	7	68	174
1934...	43	53	208	589	1	3	43	151
1935...	33	43	180	601		2	49	169
1936...	31	44	185	587	3	8	25	130
1937...	36	52	263	754	1	4	113	288
1938...	26	38	166	540	2	2	72	151
1939...	28	49	205	574	1	2	50	211
1940...	19	30	243	756	3	7	49	153
1941...	31	42	220	739	5	5	56	94
1942...	35	51	155	931	2	6	41	141
Total	428	615	3,087	9,521	32	62	877	2,453

Table 1 shows that in 1930-42, inclusive, 428 fatalities are charged to contact with the trolley wire in bituminous mines and 32 in anthracite mines or 460 all told, an average of 35 a year. If the fatalities caused indirectly by electric shocks from the trolley system as discussed in the foregoing were added, there is good reason to believe that because of contacts with the trolley system at least 50 men on an average have been killed annually in the coal mines of the United States for the past 13 years and probably for at least 20 years.

Cash,[4] in a study of fatalities from electrical contact in the coal mines of Alabama for a 15-year period, found that 75 out of 98 fatalities or 77 percent of all fatalities caused by electricity were due to direct or indirect contact with 250-volt d.c. bare trolley wire. The proportion of fatalities caused by electricity to all fatalities was about 12.6 percent, which is far above the Unites States average, trolley wire alone being responsible for approximately 9 percent of all fatalities in Alabama coal mines during that period. These high percentages are due largely to the thin, pitching coal beds and high humidity of the year-around climate. The height of the trolley wire was known in many of these fatalities; it was found that 67 percent occurred where the trolley wire was less than 5 feet above the rail, 33 percent occurred where the trolley wire was 5 to 6-1/2 feet above the rail, and no accidents were known to have occurred where the wire was 6-1/2 feet or more above the rail. Approximately 38 percent of these accidents occurred where the trolley wire was 4 to 4-1/2 feet above the rail and only two where the trolley wire was 6 to 6-1/2 feet above the rail.

This study of the height of the trolley wire in relation to contact fatalities in Alabama is undoubtedly representative of what occurs in other mining States and calls attention to the hazards of low, unguarded, bare trolley wires. It also justifies the conclusion that where trolley wires are less than 6-1/2 or 7 feet from the rail they should be guarded from contact by persons throughout every foot of their length.

Studies and analysis of 112 fatal shock accidents in and about the coal mines in the United States over a period of several years, taken from the reports of detailed information submitted by companies that entered the National Safety Competition, show that 89 were attributed to trolley wires and trolley-pole accessories. These companies had a much more than ordinary interest in safety and accident prevention; nevertheless, 80 percent of the electrical fatalities resulted from the trolley wire. A logical inference to be drawn from this study involving coal mines using extraordinary precaution to operate mines safely is that the trolley system is so inherently unsafe that even these ultra-safety-minded coal-mining organizations could not make it reasonably safe.

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[4] Cash, Frank E., Fatalities Caused by Electric Contact in Alabama Coal Mines, 1925-39: Bureau of Mines Information Circular 7120, 1940, 20pp.

The trolley wire is no respecter of positions or occupations in choosing its victims; a study of these accidents reveals that they include officials as well as miners. The fatal shocks are received in many and various ways of touching trolley wire. Some of these fatalities result from the indifference, negligence, or carelessness of the workmen, but usually they are caused by the lack of guards and the lowness of trolley wire. In spite of the number of deaths caused by contact with trolley wire, there are many - both officials and miners - who do not regard it as dangerous or realize its deadly effects. The voltages used in the trolley system range from 250 to 550 volts d. c., high enough to cause instant death. (Many deaths have been caused by 110 volts, and there are records of deaths caused in mines by contact with circuits carrying only 50 to 60 volts alternating current.) It is a very dangerous fallacy to regard trolley wire, even when carrying only 250 volts, as anything but dangerous. Records of the past prove that trolley wire has caused many more fatalities than any other type of electrical equipment used in coal mines; in fact it has probably caused more fatalities than all other types of electrical equipment and devices combined.

Many accidents caused by trolley wire are charged to haulage. The exact number cannot be determined, but if it were possible to investigate them properly the number (especially members of the locomotive crew) would be quite large. Many of these accidents occur when a trolley pole jumps the trolley wire and the motorman or brakeman, in attempting to reach the trolley pole, strikes the trolley wire, is shocked, and is knocked or falls off the motor. Injuries have also resulted when the motorman's head strikes a timber or roof projection while he attempts to replace the trolley on the wire, causing him to fall under the motor or moving cars. Back-poling, which is contrary to all safety rules, is another source of injury and death to motor crews. The following are typical examples.

1. A rock-dusting crew of three men was using a haulage locomotive to ride out of the mine. The workman operating the locomotive, who was inexperienced, became frightened when the starting box blew up while he was operating the controller and jumped off the front of the moving locomotive, which ran over him, causing his death.

2. A motorman with 21 years experience was killed instantly when he was pulled over the top of the locomotive by the motor cable of a cable-reel locomotive.

The locomotive had placed empties and returned to the entry, where the nips had been hooked over the trolley wire, the latter was on the right side of the entry and the cable guide on the left side of the locomotive. The investigator believed that the motorman removed the nip from the trolley wire and was using it to speed up the motor by "nipping" when it caught in a hanger and the cable dragged him over the top of the motor. The height of the locomotive was 31 inches and the clearance over the rail 37 inches.

3. While operating a locomotive, a motorman was fatally injured when he was knocked (or possibly fell) from the locomotive. The man who reported

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on this accident believed the motorman suffered an electric shock which caused him to fall under the locomotive.

4. A motorman's lamp battery came in contact with the transfer switch of the locomotive and when attempting to escape the arc, the motorman fell in front of the moving locomotive.

5. An improperly insulated splice in a pole cable arced at the base of the pole; the motorman, apparently in trying to escape by getting off the front and without closing the controller switch, was run over by the locomotive.

The following are a few examples of accidents caused by contact with trolley wire:

1. A miner on his way out of the mine, in crossing between cars at the cross-over near the shaft bottom, came in contact with the 250-volt trolley wire directly over the cars and was electrocuted. His clothing was wet with perspiration, and the car bumpers were of steel.

2. A Joy loading machine was being moved along an entry, and the machine handle did not clear rib. The operator, sitting on the machine and reaching for a pick so that the place would be made wider, touched the 500-volt trolley wire with the back of his head and was electrocuted. The wire was 5-1/2 feet from the rail, and was unguarded.

3. A coal loader loading chunks of coal into a car touched a 250-volt trolley wire with the back of his neck. The trolley wire was not guarded and was only 52 inches above the rail.

4. Eight loaded cars were being pushed in an entry used as a storage track when the fifth car was derailed. The brakeman placed a block under the derailed car and, in backing out between the cars, came in contact with the 550-volt trolley wire. The trolley wire on the straight track was 5 feet 8 inches above the rail and protected with guard rails, and the wire in the storage entry was 4 feet 2 inches above the rail and unprotected. It is believed that the brakeman, in climbing over the cars backward, struck his head against the guard boards, which threw him forward, striking his head against the unguarded wire.

5. An empty car had been derailed on a side track. The miner was using a piece of timber as a lever to rerail the car; as he raised up to adjust the block, he came in contact with the trolley wire was electrocuted.

6. A miner on his way to an adjoining room stepped under a trolley wire to let a gathering locomotive pass. As he stepped back to the track, he came in contact with the trolley wire and was killed.

7. A brakeman was riding on top of a locomotive when the trolley pole came off the wire. While attempting to replace it, he came in contact with the 550-volt trolley wire and was electrocuted.

8. A miner was carrying a drill on his shoulder; in passing a trip the drill hit the trolley wire, which was 58 inches above the rail. The miner was killed.

Remarks

The above accidents typify the hundreds that have resulted from contact with bare trolley wire. Most, if not all, fatalities from this cause are unnecessary and probably could have been prevented by shielding or guarding the trolley wire. However, to be effective trolley wire should be shielded or guarded throughout its entire length where less than 6-1/2 feet above the rail. Many mines shield trolley wire at crossings, man-trip stations, or places where men gather; this is effective as far as it goes, but as trolley wire has proved dangerous at any location, real safety requires that its entire length be protected. A mining company in a Southern State, which had experienced many fatalities from the trolley, with slightly over 100 miles of trolley wire in its various mines, took the precaution to shield approximately 85 miles of it and by so doing practically eliminated fatalities from the trolley-wire contact hazard.

Until other methods of transportation are developed and adopted that will eliminate the need of bare trolley lines, every inch of the trolley wire should be shielded or guarded if fatalities from this source are to be prevented. If the trolley system is as efficient as its proponents believe, enough of the earnings due to this effective service should be expended in trying to make it at least reasonably safe.

Ignition Hazards of Trolley Wires (And Electric Locomotives)

The greatest potential hazard of the trolley-locomotive system is without doubt, the possibility of igniting explosive gas or coal dust in suspension. The system, in common with all electrical equipment but to a far greater extent than any other electrical equipment used in coal mines, is subject to arcing or sparking that may lead to explosions in the presence of explosive gas. The contact-electrocution hazard takes a toll of approximately 50 lives a year through the trolley system, but 1 gas or dust ignition may cause 100 or more fatalities, and this has actually occurred. The ignition hazards of electrical equipment are well-recognized by those who care to consider the matter, and precautions necessary for eliminating these hazards are known by many, perhaps most, coal-mining men; unfortunately they are observed relatively seldom. The introduction and use of permissible electrical equipment greatly reduce the ignition hazard where it is employed (but this is relatively little). There is no record that any equipment, of this type, when properly maintained and operated, has contributed to causing an explosion. Relatively little advantage is taken of the availability of this type of equipment, and electricity continues to be by far the greatest single source of ignitions resulting in explosions in United States coal mines. Table 2 shows that electricity was responsible for approximately 45 percent of all coal-mine explosions and 57 percent of the fatalities from them in the past 15 years. The records of the war years (fiscal years

1941-44) show a higher percentage of explosions of electrical origin than the 15-year period; 58 of the 100 coal-mine explosions recorded in this 3 years, or 58 percent, resulted in 403 of the 561 deaths caused by explosions, or approximately 72 percent were of electrical origin, the source of ignition being electrical equipment. This indicates that the knowledge of past lessons and experiences has not been put into effect; it is a record in which the coal-mining industry can take little pride.

TABLE 2. - Explosions caused by trolley wires and locomotives, 1930-44; comparisons with total electrical causes and total of all causes

	Trolley-locomotive system		Total electrical causes		Total - all causes of explosions	
Year	Number	Fatalities	Number	Fatalities	Number	Fatalities
1930..........	6	26	18	154	34	199
1931..........	3	84	9	143	26	217
1932..........	2	2	10	11	33	87
1933..........	4	6	8	25	22	122
1934..........	5	13	10	21	26	28
1935..........	3	1	10	29	22	54
1936..........	2	10	5	20	25	38
1937..........	5	25	12	53	20	62
1938..........	4	16	10	24	29	170
1939..........	3	7	9	13	14	16
1940..........	0	0	6	99	18	206
1941..........	4	73	14	145	26	163
1942..........	3	9	14	133	22	152
1943..........	1	20	19	66	32	152
1944..........	5	15	11	59	20	94
Total	50	307	165	995	369	1,760

This paper does not propose to discuss electrical ignition hazards in general, but a knowledge of the record of the general electrical hazard is necessary in any presentation of the hazards pertaining to trolley-locomotive system. Trolley-locomotive system has caused more explosions than any other single type of electrical equipment used in coal mines. This may be due to several factors, the principal one being that while it is possible to procure types of permissible electrical equipment for use in connection with nearly all other equipment in coal mines trolley wire and trolley locomotives have such inherent hazards that they cannot be made permissible. This apparently is not readily recognized or realized by many mining companies. Mines that take the precaution of using only permissible equipment and are meticulous in installing other safeguards in an attempt to eliminate possible ignitions operate locomotives in return airways where accumulations of gas may be moved at any time. They fail to realize that trolley locomotives are not permissible and that there is always the possibility of ignition from the trolley poles with the uninsulated wire, open-type controls and locomotive motors, lack of bonding or ineffective bonding, possible falling of trolley wire, and numerous other ignition hazards inherent in the trolley system.

Table 2 shows the explosions and fatalities caused by the trolley-locomotive system and compares them with all electrical and total explosion causes. For the period tabulated, they have caused 13.5 percent of all explosions and were responsible for 17 percent of all deaths resulting from explosions; they have, moreover, caused 30 percent of all explosions and 31 percent of all fatalities attributed to electricity. The number of explosions attributed to the trolley systems would undoubtedly be higher if all explosions of electrical origin were properly classified, as reports of many explosions attribute the cause to an electric arc, not designating the type of equipment. Trolley wires were suspected as the cause of many explosions that are not included in the above.

Explosions attributed to the trolley-locomotive system have occurred yearly (except in 1940), accounting for many deaths. Except for a few years, the death toll is not great, but in most cases the explosions were prevented from spreading by rock dusting and in some places by good luck rather than consequence of precaution taken in connection with the trolley-locomotive system. Many of these explosions caused no loss of life and resulted only in nonfatal burning of the victims. The direct ignition of gas by the trolley system is by no means negligible, but the direct or indirect ignition of coal dust is the greatest danger from this system. The right combination for an electrical ignition of coal dust occurs relatively seldom, but it is comparatively easy to ignite a small pocket of gas, which in turn may stir up enough dust to propagate an explosion throughout a mine; therein lies one of the greatest dangers of the trolley system, since the source of ignition (flame, arc, or spark) may always be present wherever trolley wire extends in a mine. In the following examples, several ignitions of small pockets of gas by trolley wire are given, but fortunately coal dust was not ignited to propogate or extend the explosion.

Explosions Caused by Trolley Wires or Locomotives

In the following examples of explosions contributing factors to the ignition of the accumulated gas were substandard ventilation practices, interrupted ventilation, or inadequate ventilation poorly distributed or controlled. Nevertheless, a trolley wire or locomotive was the source of the ignition; neither should be used where gas are likely to be liberated.

Ignitions or explosions caused by arcing of the nips on the trolley line while a mining machine or other equipment was trammed, arcing of the nips hung on the trolley wire from a cable-reel locomotive, or of a mining machine while cutting are not given in the following examples.

Arcs from Trolley Wheel Igniting Gas

One of the worst hazards of the trolley-locomotive system is the arcing or sparking of the trolley wheel or harp while sliding along or touching the trolley wire, and most of the explosion attributed to the trolley system result from the ignition of explosive gas by arcs given off at the trolley wheel. Some explosions from this cause are described in brief:

1. A body of gas in a coal mine haulageway, ignited by an arc from a trolley locomotive - probably a spark from the trolley wheel - killed 63 men at about 10:40 a.m. during a day shift. Eighteen men escaped from the explosion area, and 12 others in the same split escaped unaided. About 350 men were in the mine at the time of the explosion.

A trolley locomotive gathered loaded cars in the entry, after it had picked up the loads, an explosion occurred when it reached the intersection of the entry and the main haulageway. A cave in a room about 250 feet outby the explosion forced an explosive mixture of gas into the air current, which passed over the locomotive and was ignited; the haulageway was on the return side of the air current. Two miners who escaped were about 500 feet outby the locomotive; they saw a flash of flame at the locomotive immediately before the force of the explosion knocked them down.

Doors on the haulageway were found held open with latches, short-circuiting the air entering the section where the explosion occurred; this is one of many caused by gas that accumulated when haulage crews latched doors open on haulage roads.

2. A spark or arc from the wheel of a trolley locomotive ignited an accumulation of gas a short distance in a tunnel off a road that was supposedly on intake air. Three men were killed, and three injured; the other men in the section escaped unassisted. Several days before the explosion a regulator had been built and placed in operation, but no tests had been made as to its effect on the ventilation.

3. A trolley locomotive used in delivering a load of pipe in an entry ignited an accumulation of gas, causing an explosion that took the lives of two men, including the supply-crew foreman. The accumulation of gas resulted from interrupted ventilation, probably due to a door being left open.

4. An arc between the trolley wire and the trolley-pole harp of an electric locomotive ignited methane that had accumulated in a high place in the roof near the top of a hill in a crosscut between the intake and return. Two men - a brakeman and a supply man - were killed; but 28 others, all within 1,000 feet of the explosion, were uninjured. These men were recovering rails, ties, trolley wires, etc., near the connection of two mines about 4 miles from the drift mouth. The gas accumulated when the haulage crew left a ventilation door open.

5. A spark from the trolley wire or an electric arc from the locomotive ignited a body of explosive gas that leaked out on the main haulage road, causing an explosion which killed eight men; two others escaped by coming out of the air shaft. All bodies were recovered except one, which could not be found after a search of several weeks. The mine was abandoned and sealed thereafter.

6. A pocket of gas, opposite a crosscut where a temporary brattice was being removed, was ignited by an arc or spark from the trolley wheel of a

passing locomotive, and two men were slightly burned. It is believed that gas accumulated beyond the last crosscut and behind the brattice being removed and that moving the locomotive inward forced the gas into the haulageway. This section had been rock-dusted several days before the explosion, which doubtless prevented the explosion from being propagated by coal dust.

7. A gas explosion on the main haulage road about 1,000 feet from the bottom of the intake shaft resulted in the death of one man by burns and violence and the serious burning of six others, one of whom died later.

A door with an 8-by 10-inch opening was erected across the main-entry intake about 1,000 feet from the shaft and was closed from the end of the second shift until the fire boss had completed his inspection. A high place in the roof about 15 feet above the track extended about 150 feet outby the door.

Statements of the injured men were that two locomotives, one carrying the fire boss, were traveling close together toward the shaft bottom; one of the men got off the first locomotive to open the door, and as the locomotive pulled through the door the explosion occurred. Explosive gas was found later in the roof cavity.

This mine used permissible mining machines and drills at the face, permissible cap lamps, and water on cutter bars; blasted with permissible explosives; and employed trolley locomotives for main-line haulage and flame-proof cable-reel locomotives for gathering.

8. Two men, the crew of a locomotive, received first-degree burns when an arc from the trolley wheel ignited gas along the haulageway. The motor road was on one of six parallel entries and on return air. Another entry was being driven parallel to the "motor" road, and just before the explosion broke through into the main return air course, short-circuiting the air from the "motor" road. This entry or air course was being driven so that the motor road could be operated in the intake air.

9. An ignition of gas in a drainage tunnel connecting two mines resulted in the death of one man, a fire boss. The ignition was caused by an arc when the trolley wheel of a locomotive ignited an accumulation of gas on the crest of a hill. Apparently the fire boss was using the locomotive in making his examination, a practice that has been the direct or indirect cause of numerous gas ignitions by trolley locomotives. Some of these ignitions have caused severe explosions.

10. A spark or arc from a trolley wheel ignited a pocket of gas in a roof cavity within an air lock on a main haulage road, killing one man and burning two others severely. The air lock (191 feet long) had been completed about 4 days before the ignition. Air locks on haulage roads are advisedly safety precautions; but the region between the doors should be well-ventilated, especially if there is a roof cavity between the doors.

11. A fire boss was killed when an accumulation of gas was ignited by a spark or arc from the trolley wheel of the locomotive he was using in an abandoned section of a mine through which return air from the active sections was coursed. The track and trolley wire were left in this section due to the possibility of reopening it in future, but a cut-out switch was placed in the trolley line near the mouth of the entry. A fall of roof tore down a stopping short-circuited the ventilation; gas accumulated at the point where it was ignited.

Remarks

The above instances are but a few of the scores of explosions in which accumulations of gas have been ignited by an arc formed by a trolley wheel or harp with trolley wire. Several explosions could have been prevented if the trolley wire had been removed or cut off abandoned or worked-out entries where there was little or no maintainence of the trolley line. Some of the explosions cited occurred in the main-line haulage, illustrating the danger from ignition in any part of a mine where trolley wire is used.

Falls of Trolley Wires

The danger of an explosion being caused by the arc formed by trolley wire is not confined to high places in the haulage road, as is shown by the following two cases where gas was ignited by a fallen trolley wire lying along the floor:

1. Eighty-two men were killed in a gas and dust explosion when an electric spark or arc from a trolley wire that had fallen to the floor ignited an accumulation of gas. There were 222 men in the mine; 119 escaped with little or no assistance; 2 were rescued immediately after the explosion; and 19 men were rescued from behind a barricade.

The point of ignition was about 160 feet from the face of an entry that had been inactive over 6 months. A small roof fall pulled out a trolley hanger, allowing the trolley line to touch the rail, causing arcs or sparks that ignited an accumulation of gas. Although the entry was idle for over 6 months the power had been left in the trolley line. The cause of the gas accumulation was short-circuiting of air that normally was coursed through the section where the explosion occurred.

2. A gas explosion occurring a few minutes before the start of the second shift in a coal mine and a short time after the arrival of the man-trips in a section killed 20 men; there were 73 in the mine, and 53 escaped uninjured without assistance.

State and Federal representatives investigating this explosion attributed the cause to a fall of roof bringing down a 550-volt trolley line which came into contact with the track rail, causing an arc that ignited the cloud of coal dust thrown into suspension by the fall in air contaminated with methane. Coal dust carried the explosion to other areas of the mine.

Remarks

Explosions of this type can occur in any section of a coal mine, regardless of the presence of gas. In the second case above an explosive mixture of gas was not present, but air containing methane greatly accelerated the ignition of coal dust. A fall of roof throwing dust into suspension and an arc from a fallen trolley wire are a probable combination in any part of a coal-mine trolley-locomotive haulage road. If conditions are favorable, an explosion is likely to occur, and an arc from a fallen trolley wire in the presence of explosive gas can have but one result - explosion.

Dust Explosions - Ignition by Trolley Wire

Coal dust raised by a runaway trip or dust thrown into suspension by a wrecked or derailed trip knocking out timbers in the presence of an electric arc or spark may cause an explosion. The presence of an explosive gas is not needed, for coal-dust explosions have occurred in the open at tipples and refuse banks when an electrical arc or burning material ignited the coal dust in suspension. A trolley wire falling and touching a rail or sagging and touching a steel car forms arcs or flashes that can ignite dense clouds of coal dust. The next three examples illustrate this type of explosion.

1. A coal-dust explosion occurred in a western coal mine, resulting in the death of 120 men underground at the time. The point of ignition was on the main haulage entry about 1,600 feet from the mouth of the mine. This entry was also the main intake air course for the mine and carried about 100,000 cubic feet of pure intake air per minute at the time the explosion occurred. The cause of the explosion was ignition of coal dust by electric arcs from short circuit of trolley wire and trolley feed cable, which fell upon steel cars because of timbers dislodged by derailed cars.

A trip of loaded cars was being pulled to the outside by a trolley locomotive. The cars next to the locomotive were loaded with machine cuttings or "bug dust." Evidence showed that the first few cars were off the track and pulled over the ties for about 100 feet and that some cars in the middle of the trip had derailed, pulling out several sets of timber, which let the trolley wire and 400,000 circular-mil bare-stranded trolley feed cable down on the end of the steel cars. The dust for ignition was supplied by very finely divided settled dust on the dislodged timbers, together with dust thrown into the air from "bumping" of the derailed cars of machine cuttings over the ties for over 100 feet. The haulage entry was very dry and dusty, and although the point of origin was only 1,600 feet from the mine portal the explosion accumulated so much momentum in the 1,600 feet before it reached the surface that it completely obliterated the concrete of a portal extending 25 or more feet into the main entry.

2. A local dust explosion caused the death of one man by asphyxiation and the serious burning of another. Fifty-one men in other parts of the mine escaped uninjured about 2 hours after the explosion.

The explosion was caused by a broken trolley wire arcing on the side of a steel car in the presence of a cloud of fine dust released from timbers and lagging dislodged by derailed cars of a pushed trip of loaded cars of coal. The explosion was local in extent involving only about 300 feet of haulage entry and rock slope. Thorough rock dusting of the haulage road and the wetness of the region prevented a major explosion, with probable large loss of life.

3. A coal-dust explosion resulted when derailed mine cars pulled a leg from under a steel crossbar; the crossbar fell on the trolley wire, causing an arc that ignited coal dust released or thrown in suspension by the falling crossbar. Four men were killed, 87 escaped unaided, and 4 were rescued by the recovery crew; 32 men barricaded themselves for a short time and were later led to safety.

The explosion occurred on the empty-car track about 350 feet from the coal dump near the bottom of the hoisting shaft. Considerable dust was made at this point from the dumping of coal, and much of the dust was carried by the intake air and deposited along the empty track. Extension of the explosion undoubtedly was stopped by rock dust.

Remarks

Coal-dust explosions are likely to occur in any part of any bituminous-coal mine where trolley wire is used. Cars may be derailed or wrecked at any point on the haulage system, knocking down timber and the trolley wire, or a small fall of roof may occur, bringing down the trolley wire and simultaneously stirring dust into the air. Many different factors, over which there is little control, may cause such a derailment or wreck; these include a broken car wheel, broken coupling pin, broken rail, and scores of other unforseen conditions.

Two of the above explosions occurred in the main intake air of the mine where the air velocity was high, with the suspended dust carried to all parts of the mine in the air current. Fortunately, adequate rock dusting can greatly limit an explosion once it is started, as amply demonstrated in the last two instances.

Arcs from Locomotive Parts Igniting Gas

Many explosions have occurred due to ignition by arcs from various parts of trolley locomotives. The wheels of locomotives in contact with poorly bonded or unbonded track or at a broken rail may arc; and arcs and sparks are given off at the motors and controllers and at times at the grids. Any of these arcs occur in the presence of explosive gas, and under certain conditions dust clouds will cause an explosion.

1. Four men were killed in a "nongassy" mine by a gas and dust explosion when an arc from a cable-reel locomotive ignited a small pocket of gas near the face of an entry. The locomotive had placed an empty car at the face, which was about 86 feet ahead of the last open crosscut, and when it

had traveled about 12 feet the explosion occurred. The explosion occurred about 9:30 a. m. The reel and bumper of the locomotive were found burning after the explosion, and the fire was not extinguished until about 5 p. m. In this case the mine management evidently depended too much on the "nongassy" designation of the mine; otherwise a cable-reel locomotive certainly ought not be used to handle cars to or from a working face.

2. A local gas explosion during the third shift about 2:20 a. m. killed 12 men; 6 or 7 are reported to have escaped uninjured.

The report of the investigators of the explosion stated that the most probable causes were: (1) An extensive cave in the pillar section threw a cloud of coal dust into suspension, and an arc given off by a cable-reel locomotive, as the motorman was "stinging" the wire, ignited the dust; (2) gas may have been liberated by a fall, and either an arc from defective bonding or from a trolley locomotive may have ignited the gas.

3. A motorman was killed by an explosion when an accumulation of gas in an entry was ignited by a haulage locomotive. The explosion occurred in an entry containing 15 rooms, the last 8 of which were worked out except for a few pillars. The motorman gathered some empties from near the face of the entry, and the explosion occurred when the locomotive was halfway out of the entry. It is believed that a fall in a room or movement of the locomotive up and down the entry forced the gas out on the haulageway. The haulageways are on return air; the mine was well rock-dusted; and the trolley wire was 6-1/2 feet above the rail. The explosion occurred about 1:30 a. m., when only the fire boss and night foreman were near this section of the mine. Many lives probably would have been lost had the explosion occurred during a working shift.

4. A local gas explosion, occurring about 3:30 a. m., caused the death of eight men; one man, seriously burned, was rescued about 4 hours later; and three men were burned but escaped unassisted. The explosion, which originated in a room, was caused when the heated resistance coils on an open-type locomotive ignited gas. The resistance on a cable-reel locomotive, which was delivering cars to the face of a room, became overheated and set fire to oil on the coil plates. The fire was extinguished with sand, and the locomotive proceeded into the adjoining room where gas was ignited while cars were being delivered to the face of the room.

5. A local gas explosion killed three men and injured another. The gas was ignited by a spark or arc from an open-type cable-reel locomotive; a feeder was discovered opposite the locomotive after the explosion. An arc from one of the motors or the controller may have ignited the gas; or, inasmuch as no bonding was done in the entry or room, an arc at a wheel may have ignited the gas.

Remarks

In several of the above instances the explosions occurred near the faces of rooms where gas was ignited by arcs from a cable-reel locomotive. Locomotives of this type present essentially the same hazards as trolley locomotives, and many explosions have been attributed to them, some with considerable loss of life. Although there is no pole or wire to arc, considerable arcing and sparking may occur at the wheels, controllers, or motors if the tracks are not bonded when a single-conductor cable is used, and explosions have been caused by arcing of the cable nips where they were hung or attached to the trolley wire.

Fire Hazards of the Trolley-Locomotive System

Fire is an ever-present hazard in a coal mine and is especially dangerous to handle because mishandling may cause an explosion.. Once an explosion has occurred the main hazard is over, unless it has started fires, introducing the possibility of another explosion. The combustible nature of coal and of the materials necessary for extracting coal, such as timber, explosives, and other flammable substances, and the constantly increasing use of electrical equipment, with its ever-present sources of ignition, tend to make fire a constant threat to all coal-mine operations. In addition, there are such sources of ignition as smoking, open lights, and welding equipment, all capable of causing disastrous fires. Hundreds of coal-mine fires probably occur yearly in the coal mines of the United States and are quickly extinguished or controlled and never reported. Nearly all experienced coal-mining men acknowledge the frequency of fires. Relatively few are called to the attention of the outside world, for unlike mine explosions, which generally cause loss of life, they result in few fatalities, although they always present the possibility of a disaster.

A coal-mine fire is generally discovered soon after it starts, and the workers can escape before it gains headway; however, a mine fire always presents a serious hazard unless it is detected quickly and handled promptly and effeciently, and it always has the potentialities of causing heavy loss of life and tremendous property damage. Even if there is no loss of life, the property damage is likely to be considerable, miners lose their wages, and production stops, during the fighting of the fire or the sealing of the section on fire or the mine. A cost of $25,000 in connection with a mine fire is by no means abnormal, and many mine fires cost $100,000 or more.

One of the greatest dangers of a mine fire is asphyxiation of the men by smoke or fumes, often in distant parts of the mine. However, for the past 20 or more years (and until the past 2 or 3 years) the coal-mining industry of the United States has been fortunate, as fatalities resulting from fires have been few. Nevertheless, a mine fire in any place or at any time is always dangerous and creates numerous hazards when attempts are made to extinguish or control it, Men may be injured or killed by falls of roof while fighting, sealing, or unsealing the fire, or explosive gas or coal dust may be ignited. A small gas explosion may ignite coal dust; or a fall of

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roof may throw dust into suspension which may be ignited by the flames of the fire and produce a widespread explosion. All of these contingencies have actually occurred. Such products of combustion from the fire as smoke, fumes, and toxic gases (for example, carbon monoxide) are hazards that are almost sure to be encountered while attempting to fight a fire or constructing seals to control it. Within the past year 16 men were killed by an explosion when they were underground trying to extinguish a mine fire that had been discovered a few hours before; the fire had been started by a short circuit by a trolley wire.

Electrical equipment has greatly increased the potential hazards of coal-mine fires. Before its introduction many fires were caused by open lights, use of black powder, smoking, and other sources of ignition; but in modern mines, where most of these have been eliminated, electricity or electrical equipment now constitutes a most prolific and almost universally prevalent source of ignition. As was found in the study of coal-mine explosions, the trolley-locomotive system also causes more fires than any other type of electrical equipment. Table 3 gives some available data on mine fires and shows the number of fires caused by the trolley-locomotive system, as well as the total of fires of electrical origin and total number of fires from all causes for the fiscal years 1930 to 1944, inclusive. This table was compiled from information about fires called to the attention of the Bureau of Mines or fires the Bureau of Mines helped or assisted in fighting or controlling. As previously stated, hundreds of fires probably occurred of which the Bureau of Mines was not informed. This table shows that the loss of life from fires started by trolley wires was small until the past few years; since that time such fires were responsible for practically all of the deaths attributed to fires of all causes.

More deaths were caused by mine fires in the 19-month period January 1, 1943, to July 31, 1944, than in any like period since the Bureau of Mines was established. In this period 104 deaths resulted from fires, including 101 caused by four fires originated by trolley wires or trolley locomotives, all in highly mechanized mines. Trolley wires have been responsible for more reported fires in this 19-month period than have occurred in the previous 10 years; 15 of the 41 fires reported were caused by the trolley wire, and in the same period other electrical equipment caused 4 fires.

The large number of fires and large loss of life caused by trolley wire in recent coal-mine disasters has focused the attention of many mine officials on the cause of these fires and methods of preventing or eliminating them.

TABLE 3. - Coal-mine fires caused by trolley wire or locomotives, 1930 - 44 comparisons with total electrical causes and total of all causes

Year	Trolley-locomotive system		Total electrical causes		Total--all causes	
	No.	Fatalities	No.	Fatalities	No.	Fatalities
1930..............	5	2	8	2	19	4
1931..............	2	0	7	0	21	7
1932..............	0	0	5	1	17	1
1933..............	1	0	7	0	20	1
1934..............	1	0	4	0	18	6
1935..............	2	0	11	11	17	11
1936..............	3	0	7	1	16	4
1937..............	2	[1] 9	5	9	15	11
1938..............	2	0	6	1	20	4
1939..............	1	0	7	1	15	2
1940..............	0	0	5	2	16	2
1941..............	1	1	7	2	13	2
1942..............	3	1	9	4	26	21
1943..............	3	13	6	13	21	15
1944..............	6	[2] 22	9	22	24	24
Total	30	48	103	69	278	115

[1] 9 men overcome with carbon monoxide while attempting to seal the fire.
[2] 16 men killed by explosion while fighting fire.

There are various ways by which the trolley-locomotive system starts fires, but the most common is a fall of roof or timber that brings down the trolley wire, short circuiting it; a wrecked trip touching a trolley wire; or a short circuit caused by a trolley wire touching part of a door frame, coal rib, or timber. Fires also have been caused by the arcing of track bonds or broken rails; leakage from insulators on trolley hangers; and a locomotive setting fire to timber or coal. The occurrence in coal mines of fires initiated by short circuits caused by falls of overlying material (rock, coal, timber, etc.) is a possibility at almost any time throughout the entire length of all trolley wires having electrical power in them. This causes the trolley system to be one of the worst hazards in present-day coal mining in the United States.

Fires Caused by Fall of Trolley Wire

A fall of roof, top coal, or timber bringing trolley wire in contact with the rail or a steel car or a steel band on a combination wood-steel car and thereby short-circuiting the trolley line is the outstanding cause of fires started by the trolley-locomotive system, especially during recent years.

1. A serious fire caused by a relatively minor fall of roof bringing the trolley wire in contact with steel mine cars was discovered by a pumpman

who was passing near by. The fire was on the main intake, and attempts were made to fight it direct with rock dust; but explosive gas was detected in the return from the fire zone, and all men were ordered out of the mine. The mine was sealed at the shaft and slope entrances with loss of production and other costs.

The power was not cut off the mine at the end of the shift and is a by no means unusual cause of fires of electrical origin.

2. A fire discovered by a locomotive crew about 2:00 a.m. was caused by a fall of roof knocking down a trolley wire, igniting timbers and two cars of coal that were under the wire. The electric mine circuits are not sectionalized, and the bonding was poor.

The locomotive crew fought the fire unsuccessfully, and eventually the fire region was sealed. The mine foreman was overcome and killed when he attempted to reach the fire against the advice of men who had been fighting it.

3. A fire was discovered by a machine helper on the night shift who was looking for the cause of a power interruption. The fire was on the entry where a fall of roof had forced down the trolley wire, causing a short circuit. Prompt action by outside help quickly extinguished the fire; fortunately, the 17 men working inby the fire were not affected.

4. A fire caused by an arc formed when a fall of "cap" coal carried the trolley wire against the rail was discovered in a mine about 7:00 a.m. It was impossible to reach the fire area a short time later, and the section was sealed by the construction of 11 stoppings. About 3 months after the seals were erected the region was unsealed, and production was resumed. No lives were lost, but the cost ran into thousands of dollars.

5. Two fires occurred almost simultaneously near the faces of a set of five main entries during the night shift, about 11:00 p.m. One of the fires, a minor one, occurred at the nips of the mining machine inby the third crosscut from the face of a main entry and the other at the second crosscut from the face in a main haulage entry from a fall of roof coal and rock on the trolley wire. The 49 men in the mine when the fires started escaped without injury.

A crew was organized to fight the fire, and the 16 men who reentered the mine were killed by an explosion which occurred about 1:00 a.m. The explosion traversed the entire mine and did extensive damage on the surface. Additional explosions occurred on the two succeeding days during the erection of seals, and several workers narrowly escaped death. The mine portals were sealed without recovering the bodies.

About 4 months later the seals were removed and the bodies recovered. The investigation revealed that the fire at the machine nips was approximately a foot in diameter, but much evidence of fire was found near the point where the fall was on the trolley wire and the return cable, and the fire radiated from this point.

6. A trolley wire falling against four cars of horse feed near the bottom of the hoist shaft ignited the cars, which started a fire about 7:10 p.m. and took the lives of six men. The cars were enclosed and constructed of yellow pine lumber, and when the wire fell the motorman jerked them from beneath the wire to a place reported to be heavily timbered and lagged. One hundred and fifty-one men escaped uninjured, but 6 men working on the main haulageway about 1,500 feet inby the fire presumably were suffocated. It was impossible to reach the section where these men were working.

The fire gained headway rapidly and was soon out of control; it was feared that accumulated gas in the nearby, unsealed, abandoned workings might be drawn across the fire so it was decided to seal the mine. The bodies were not recovered at the time, and sealing of the mine openings was begun about 17 hours after the start of the fire; the bodies were recovered several months later.

7. When a face boss smelled smoke it led to the discovery of a fire on a haulage entry (return air) caused by a fall of roof knocking down the trolley wire. The mine was idle on the day of the fire, although a few men were working.

The fire was of such magnitude that the face boss telephoned to the surface for additional help.

Several rescue teams with oxygen breathing apparatus were taken into the mine on several trips near the fire. Between 15 to 20 men were on these trips, and all were more or less affected by carbon monoxide; all but 9 managed to make their way into the parallel air course and were rescued by fellow workmen; 9 men lost their lives. Rescue men wearing oxygen apparatus recovered the bodies of the 9 men, and it was reported that 24 were treated for carbon monoxide poisoning during recovery operations.

During the recovery of the bodies the fire had gained such headway that the seal already started could not be finished, and it was necessary to erect seals farther back to enclose the fire region.

A fire was discovered about 11:15 p.m. by a night foreman when he opened the door of a main haulage road between two entries. The fire was burning on both sides of the entry and an air course. Eighteen men working inby the fire erected a barricade and were rescued approximately 13 hours after the fire was discovered.

A fall of rock on the trolley wire had caused a short circuit, which ignited either a crib or the trap door at the point of origin of the fire. No other sources of ignition were known to be present. After the men were recovered it was found necessary to seal the mine at the surface openings. Six seals were erected.

9. The following fire resulted from a fallen trolley wire but, unlike the fires previously described, the fall of roof was man-made and not, as in most cases, a natural fall of roof or coal; the results and effects, however, were the same, indicating the many ways trolley wire can be short-circuited and cause a fire.

A timberman "scaling" roof caused a roof fall, which broke the trolley wire and allowed it to come in contact with the rail. The timberman pushed the trolley wire against the rib and went about 1,000 feet to open a circuit breaker. The fire caused by the trolley wire spread rapidly. Sixty-six of the 185 men in the mine were trapped inby the fire. Unsuccessful attempts were made to control the fire and to reach the men inside. Sealing of the fire area was started; but an increased gas content made it necessary to withdraw the recovery crew to the surface, and the mine was sealed at the surface openings, with the 66 men inside. Futile attempts were made to reach the entombed men by drill holes from the surface, and all 66 perished.

This fire occurred in one of four parallel entries and on the intake air.

Remarks

The above are but a few of the scores of fires started by short circuits in trolley lines caused when falls of roof, coal, or timber brought down trolley wire. These fires show that trolley wire is an ever-present threats of fire in all parts of the mine where it is used, as essentially no part of a coal mine is free from possibility of falls of roof or top coal. Many of these fires occurred on the main haulage roads on intake air, and although there was loss of life in only a few of them the property damage and loss of production in all were considerable.

Several of the fires illustrate the hazard of combatting fires; in most of these fires the workers reached safety when the fire was discovered, but fighting the fires cost lives. Many of the fires occurred during the night shift and resulted from not cutting the power from electric circuits in idle sections; however, the deaths occurred in connection with fires that were discovered when the wire fell.

Fires Caused by Wrecked or Derailed Cars

Many mine fires are caused by wrecked or derailed cars coming into contact with the trolley wire or feed cable or knocking out timber, bringing down the trolley wire, which is short-circuited and starts a fire. Usually, these fires are quickly controlled or extinguished, but the following three fires show how easily a very costly fire can be initiated.

10. A fire was discovered about 5:45 a. m. by a pumpman when he entered the mine to start a pump. This section was not being worked, and the entry was used for car storage. There were 144 cars in the entry when 43 loaded cars were added, and it was necessary to push all of them farther into the

entry to clear the main line. Unknown to the locomotive crew, 3 cars on the far end were derailed and pushed against the 550-volt trolley wire. After pushing the trip, the crew left the region and did not pull the section switch for the storage entry; the automatic circuit breaker did not open, and the wire touching the metal on the mine cars burned in two.

Efforts to fight the fire were unsuccessful, and the fire region was sealed. Fortunately, no one was injured during the fire or sealing operations.

11. At the end of a shift, a fire was started in the main haulageway by a wrecked trip that brought down the trolley wire. A heavy arc was formed, which ignited the coal in the loaded cars when the motorman jerked the trip from under the wire. The power was cut off by cutting the wire, but natural ventilation permitted the fire to gain headway. A brakeman lost his life attempting to recover fire-fighting equipment when smoke and fumes forced the locomotive to be withdrawn.

An extensive territory was sealed, and 7 years later when attempts were made to recover the section the fire was still burning. The section has never been recovered.

12. A loaded 34-car trip was being hauled to the outside by a trolley locomotive when at a curve the coupling between the sixth and seventh cars came loose, and the locomotive and 6 cars ran ahead of the other 28; the latter ran down the main haulageway a short distance, where the first 6 cars derailed and wrecked. In the ensuing wreck the iron on the front end of one of the cars was forced against the trolley line and two feeder cables, causing a short-circuit that ignited the wood of the cars, the coal, or both.

The fire occurred in the middle of the afternoon and was fought by playing water on the burning coal and timbers; it was extinguished the following morning, fortunately without loss of life.

Remarks

Fires from this cause are by no means rare and constitute one of the greatest fire hazards of bare trolley wire.

Fires Caused by Contact of Trolley Wire

Trolley wire often touches wooden crossbars, door frames, coal ribs, or canvas around doors. These materials may be classed as nonconductors when dry; they may become conductors when they become damp by being saturated with humid air of a mine or otherwise, and then a leakage of current from the bare trolley wire creates a fire hazard. The sparks given off by a trolley wheel can ignite brattice cloth or canvas at door frames when they are dry, and this has occurred in numerous instances. A trolley wheel of a locomotive may strike the wood of a door frame or timber, and the resulting flash when the wheel is pushed from the trolley wire may ignite canvas or loose ends of cloth at the door; this also has occurred in many places. An overloaded trolley wire pressing against any combustible material may start a fire, and poorly installed or insulated trolley hangers have caused fires by leakage of current.

The following gives some instances of fires from these causes:

1. A fire, the control of which required the erection of 25 new masonry stoppings and the repair of 75 old stoppings, was discovered about 12:15 p.m. by two trackmen who were eating their lunch and heard a fall. There were 218 men in the mine at the time the fire was discovered, and all escaped without injury.

The fire is thought to have been started from a short-circuited trolley hanger or from a roof fall pulling down the 550-volt direct-current trolley wire, causing an electric arc that ignited the coal. The former appears the more likely cause, as no power interruption was experienced and when the trackmen heard the roof fall it was immediately investigated, and a large volume of smoke and fumes was already coming from the fire.

Less than a year before, a fire was caused in this mine by a faulty hanger, and much difficulty was experienced in extinguishing it.

2. A fire, caused by a small fall grounding the bare trolley wire against a door, was discovered about 10:30 p.m. by members of a night-shift crew at the entrance to a panel off the main haulage road. Apparently some one failed to cut the power off the trolley line when the shift was completed.

When discovered, the fire had gained headway and had burned the door, door frame, and several sets of timbers. This mine is one of the gassiest in the United States, and the fire occurred about 600 feet from the pillar line of a panel. Fortunately, the airlock system of doors was employed. The second door controlling the ventilation for this panel was about 300 feet inby the burning door, and the fire had not reached it; this inby door aided greatly in the ventilation control of the fire area and minimized the explosion hazard.

The fire was fought directly with water, and although much difficulty was experienced with falls, the fire was brought under control in about 12 hours.

Remarks

Most fires of this type are preventable. Proper installation, alinement, and maintenance of the trolley wire would do much to prevent fires from these sources.

In one of these fires the use of air-lock doors for ventilation proved effective in controlling the fire. The effectiveness of these doors is worthy of note to anyone interested in fighting or controlling fires. The most disastrous fires are those that occur on the main intake air and gain headway rapidly owing to the volume of air passing over them. A series of doors (erected in and along the main intake haulageways) which could be closed in time of a fire would not only allow men to escape and prevent fumes and smoke from reaching the inner workings but would also allow control of the volume of air reaching the fire and probably prevent gas from inner workings from finding its way over the fire.

Fires of Miscellaneous Causes by the Trolley-Locomotive System

Fires have been caused by various parts of the trolley-locomotive system other than trolley wire.

Track bonds may be a fire hazard in a mine, and the arcing and sparking of poor bonds, broken rails, or broken bonds can ignite wooden ties or coal along the track. Ignitions of this type have occurred.

Fire Caused by Faulty Track Bond

A fire was discovered by a haulage crew; the probable cause was a faulty rail bond or a jumper cable. This fire was fought direct for 3 days without success, after which six seals were erected around the fire area. Two of the seals were opened in about 2 weeks, but the fire rekindled, and the seals were replaced; two concrete dams were built and the place flooded.

Locomotives Causing Mine Fires

If an electrical fire on a locomotive spreads to the timber or coal it may cause a fire; generally these fires are quickly extinguished or controlled, but in the following case the motorman was evidently killed either by shock or falling from the motor, and the fire spread rapidly.

Smoke and fumes from fire on the trolley main haulage road killed a motorman and 12 other men about 1 to 1-1/2 miles inby the fire; 65 other men escaped uninjured. The bodies (except that of the motorman) were recovered, and the mine was sealed at the surface when, after several days, efforts to control the fire were unsuccessful.

The fire started about 2:55 a.m. near the intersection of two main haulage roads about 2-1/2 miles from the slope bottom and about 1 to 1-1/2 miles outby the working section, at a 15-ton, double-deck, dual-control trolley locomotive that was pulling a trip of 23 loaded cars to the slope bottom. The trip stopped suddenly, and the brakeman when walking from the rear of the trip toward the locomotive saw electric arcing and a fire at the locomotive but, due to smoke, could not reach the front of the trip. He then telephoned the dispatcher to cut off the power circuits in this section.

The fire was fought direct but became so serious that the mine had to be sealed at the surface; the seals were removed in about 3 months, and the mine was recovered. The section of the mine where the fire started was reached about 17 months after the mine had been sealed, and the body of the motorman and the locomotive at which he was killed were recovered. The locomotive was brought to the surface, and examination revealed that an electrical failure had occurred in the controller, inasmuch as parts of it were fused, and holes had been burned through the controller shield. When attempts were first made to combat the fire, it was found that a fall of shale and timber had pulled down the 550-volt, direct-current trolley line about 25 feet outby the locomotive. This fire cost 13 lives and tens of thousands of dollars.

Material on Supply Trip Short-Circuiting Trolley Wire

A fire, which fortunately was fought promptly but which had possibilities of causing a disaster, is described in the following:

A mine fire resulted when conveyor pans piled too high on a supply train failed to clear a steel timber and touched a 6/0 trolley wire and a 1,000,000-circular-mil return cable, causing a short circuit. The supply train contained an explosives car with 1,700 sticks of permissible explosives; a car of sand; a truck with 50 gallons of lubricating oil; two trucks each with 104 feet of 36-inch belting; and 5 cars of conveyor pans 12 feet long and 36 inches wide.

The fire occurred on the main haulage road about 30 minutes after two man-trips of the night shift had entered the mine. The 163 men in the mine escaped unassisted but had to travel through smoke, and they escaped with considerable difficulty.

Prompt assistance from the outside enabled the explosives car and car of oil, which were on the end of the trip away from the fire, to be pushed away. The fire was fought directly and extinguished in about 12 hours.

SUMMARY

A brief discussion has been given after each group of accidents described in which causes were similar; the discussion was confined largely to that part of the trolley-locomotive system which was the direct cause; and although several contributing factors were recognized, little or no reference was made to them because, regardless of inadequate ventilation, substandard practices, lack of supervision, and numerous other contributing causes many, probably all, of accidents described would have been prevented by some form of transportation or haulage other than the trolley system.

Accidents of various kinds due to the trolley system (and many others not given) show that bare trolley wires were directly involved in most of the fatal shocks, explosions, and fires caused by electricity; other parts of the trolley-locomotive system also contribute to a smaller extent.

The explosions occurred in virtually all parts of mines - some in the return air courses or near the working places and others in fresh air in supposedly fresh-air intake. They vividly bring out the hazards of trolley wires and show that the danger of igniting gas or dust by electric arc is not confined to working places. Many mining companies know and recognize the hazards of electric arcs in the face region, employ permissible equipment, and conscientiously attempt to eliminate known ignition hazards in the face region; but they use trolley locomotives and extend trolley wires close to the face as possible, in many cases operating wholly in return-air currents without regard for the potential sparking or arcing hazards. Adequate ventilation, properly controlled and coursed, would have prevented several of the explosions listed, but carelessness with ventilation on trolley haulage roads appears to be one of the most notable of the numerous incongruities in connection with safety in operating United States coal mines. Precautions usually are taken at the face region to prevent ignitions, but it is rarely realized that gas-air mixtures within the explosive range may travel a considerable distance until they meet an ignition agency, such as a trolley wire or trolley locomotive. Several explosions have resulted when an arc from a trolley wire ignited gas forced on the entry by falls or other activating cause some distance away, or in supposedly gas-free entries where gas accumulated due to short-circuiting of the air, such as might occur in an air lock between doors or in a high, unventilated place in an entry.

Any electrical installation or equipment capable of igniting gas will always be a potential ignition hazard, and this applies to all coal mines, as many ignitions due to the trolley system have occurred in so-called non-gassy mines. The coal dust of practically all bituminous coal mines can be ignited by an electric arc, and trolley wire and trolley locomotives constitute a class of installation that cannot be made permissible or safe. In other words, they are inherently unsafe and hazardous whenever used in coal mines, even in untimbered rock tunnels or other places that have in themselves no combustible matter, because loaded (or in some cases empty) cars or trips or coal that has accumulated along the floor through leaking or falling from cars supplies the flammable material.

The initiation of fire by trolley wire is almost analogous to the initiation of explosions. The causes are essentially the same - short-circuiting of trolley wire from roof falls, wrecked trips, and contact with combustible materials or equipment - the main difference being that in the presence of gas or of coal dust in suspension in air any arc formed is likely to initiate an explosion rather than merely a fire. Fires occur in virtually the same places as explosions, as they have originated in essentially all sections of mines where trolley wire extended. However, unlike explosions, loss of life from fires caused by the trolley system has been relatively low until the past few years, although the property damage has been considerable every year for the past 3 decades but greatly increased during the past 3 or 4 years.

In several fires started by the trolley system the protection circuit breakers or switches were considerable distances from the origin of the fire, and by the time they were opened the fires had gained much headway or were out of control. In some mines circuit breakers failed to operate to interrupt the flow of electricity; in many cases this probably was due to the necessity of setting the release high enough to handle momentarily heavy loads on the circuit or possibly low voltage due to a large amount of equipment in use, with the result that the amount of current passing through the path caused by the short circuit was too low to trip the release. The necessity of setting the release high because of increased equipment has greatly augmented the danger of fire and largely nullifies the protection circuit breakers should offer; even when set at normal capacity they have proved ineffective, in many cases in preventing fires from the short-circuiting of the trolley wire.

The deenergizing of the trolley circuit during off shifts or idle periods and the utilization of sectionalizing switches to remove power from circuits not being used by the locomotive probably would have prevented many fires which occurred during the night or on off shifts and burned undetected for many hours until discovered by mine officials after gaining considerable headway. The use of trolley wire as conductors for direct-current equipment, such as pumps, drills, and lights, procludes deenergizing the trolley wire when the locomotive is not in that particular section, adding to the numerous hazards of the bare trolley wire. Nevertheless, during idle periods in any section the power should be cut off that section; and power should be removed from the entire mine, so far as feasible, when men are not in the mine.

The danger of contact with or shock from trolley wire is about the only hazard of this entire system that can be partly controlled or eliminated. Guarding or shielding trolley wire where it is less than 6-1/2 feet above the rail probably would eliminate (or at least greatly reduce) the number of electrocutions and injuries from this source; however; to make this effective the wire should be shielded throughout its length rather than at certain parts of the system only. Although guarding the trolley wire probably would reduce the danger of shock and contact, the potential hazards of gas or coal-dust explosions and fires would still be present wherever wire is installed in all coal mines. However, certain types of guarding increase the fire hazard and in addition introduce a new one, inasmuch as loose or partly split wooden trolley guards have caused motormen and others to be severely injured or even killed.

Any coal-mine installation such as a trolley-locomotive system, which is known to have initiated gas or dust explosions, has originated fires, jeopardizes the life of workmen throughout its entire length by danger of contact, and has many inherent hazards that cannot be eliminated calls attention to the need of some far safer type of coal-mine haulage. Despite its numerous operating advantages, unquestionably the trolley haulage system should be superseded by some other method or methods of transportation.

POSSIBLE METHODS OF TRANSPORTATION OTHER THAN THE TROLLEY-LOCOMOTIVE SYSTEM

The trolley-locomotive system has so many advantages to mines from an operating point of view that its inherently hazardous characteristics have always been and probably for many years will be ignored. A substitute main-haulage system to supersede the trolley to any considerably extent has numerous obstacles to overcome, even though the trolley system must be recognized as one of the worst influences in any mine so far as safety is concerned. Many improvements and alterations could be made in the trolley-locomotive system that probably would avert some of the types of accidents to which attention has been called; and improvements and alterations that can be made probably will minimize some of the numerous hazards, but the system is so inherently unsafe that it is absolutely impossible to make it even reasonably safe, irrespective of any precautions that can be taken. The numerous hazards can be eliminated only by removing trolley wire and trolley locomotives from coal mines. This statement is made with full recognition of the storm of protest likely to arise in the coal-mining industry; nevertheless, it is a thought that should be considered most carefully by those responsible for taking the necessary precautions toward safeguarding both the mines and the mine workers of the United States.

Within the past 2 decades, several methods other than the trolley system of transporting coal from the mine have been in successful operation at individual mines, more especially in highly concentrated mechanized mines, all of which reduce the amount of use of trolley locomotives.

Permissible Storage-Battery Locomotives

For mines that depend on the use of tracks for primary and secondary haulage, permissible storage-battery locomotives are available; they have not been utilized in this country to any great extent for main haulage, although a few large mines in the United States use them exclusively for all underground haulage, main as well as gathering. In the United States, however, storage-battery locomotives are used primarily for gathering or secondary haulage in gassy sections of a mine. The development of quick-changing batteries similar to those used in shuttle cars should greatly encourage use of these self-contained locomotives for all mine purposes. There are no records of explosions attributed to permissible storage-battery locomotives when maintained in a permissible condition, and they have caused relatively few fires.

Among the late developments in mine haulage are rubber-tired shuttle cars, which have had some success, not only in coal mines but also in salt, potash, and bauxite mines, for gathering in cooperation with a loading unit. Some of these cars are self-contained, being powered by storage batteries, and they transport to belts or to car haulage. Cable-reel-type shuttle cars have the disadvantages of cable-reel locomotives in that there are the numerous hazards of the cable.

Conveyor Systems

Belts and chain, flight, or shaker conveyors have displaced many thousand feet of trolley wire and track and are used in both hand-loading and mechanical-loading mines. Generally the conveyor system is used for taking coal from production units or as gathering units delivering the coal to rail-haulage units or to other belt units. There are, however, several successful operations where belts are used for main-line transportation, the coal being carried several thousand feet from the face to the surface by belt conveyors; the use of conveyor equipment has enabled many mines to operate that might otherwise have been abandoned had they been forced to rely upon the usual methods of transportation.

Storage-battery locomotives have operating characteristics that make them well-adapted for gathering or secondary haulage in mines, but in general they have not been found to answer the requirements of main-haulage as well as trolley locomotives. However, some progressive mining companies have displaced trolley-locomotive haulage by storage-battery haulage because of the fire and other hazards of the trolley system.

In the past, various kinds of main haulage have been tried and abandoned; mule trains, gasoline, steam or compressed-air locomotives, and locally tail-rope haulage all have been tried, used to some extent, and then discontinued when heavy requirements were encountered or from other reasons.

Diesel Locomotive

Diesel locomotives of especial construction are suggested to replace trolley locomotives, especially for main-line haulage; locomotives of this type, when carefully constructed and operated, have proved to be economical, efficient, and safe for use in the driving some large tunnels in the United States, but numerous objections have heretofore prevented their development and use in United States coal mines. They have had Government approval and have been employed for many years in Germany, France, and Belgium, where they replaced storage-battery, gasoline, and compressed-air locomotives in gassy and nongassy mines and electric trolley locomotives in nongassy mines. They were first used in the Saar mines about 1927; their number gradually increased up to the start of the present war, and they may have been developed further during the war years. British coal mines have been slow to use Diesel locomotives underground, but a few have been placed in mines, and it is understood that one or more British machinery companies are manufacturing them for use in coal mines. In the United States, field and laboratory workers of the Bureau of Mines have been studying, investigating, and testing Diesel locomotives for underground use in coal mines for several years, and an approval schedule has been authorized for testing Diesel locomotives for use in coal mines. It is believed that Diesel locomotives will be available as soon as war conditions make the materials necessary for their manufacture available.

The locomotives used in foreign countries are of the single-, two-, and six-cylinder types, ranging from 9 to 85 horsepower. Specially designed and redesigned Diesel locomotives have been used in tunnel driving in the United States in recent years, and most of the so-called "bugs" eliminated, including those constituting the many objections against their use in this country. It is now believed that Diesel locomotives can be so manufactured as to place them on a safety scale equal to that of permissible storage-battery locomotives. The exhaust of the Diesel, when correctly designed and carefully operated, is virtually free of carbon monoxide owing to the almost complete combustion of the fuel. It has been found that the movement of about 74 cubic feet of air per minute per brake-horsepower will dilute the carbon monoxide below the percentages affecting human beings. The other toxic exhaust gases and fumes are removed or rendered harmless by dilution with air and by scrubbing devices that cool and largely deodorize them. Placing flame-arresting devices at the exhaust and intake largely, if not wholly, eliminates the gas-ignition hazard.

Frequent inspections, with proper maintenance and attention, are required to maintain this equipment in condition for safe operation, but in the countries where these locomotives are used it is said that this has presented no insuperable difficulties. From the experience gained in foreign countries and from investigations and tests by the Bureau of Mines in the laboratory and in tunnel driving in the United States, it appears that most of the objections to Diesel locomotives in coal mines have been overcome, that they offer a method of underground transportation far less hazardous than the trolley locomotive system and that they are at least on a par with trolley locomotives from the very important viewpoint of efficiency and cost of hauling material.

At present, a large coal company in the Appalachian district is considering the use of Diesel locomotives for underground haulage in two new mines, where the anticipated production of each is about 5,000 tons daily. This company contemplates using 15- to 18-ton Diesel locomotives. These locomotives are being considered: (1) To eliminate the hazards of the trolley wire; and (2) by eliminating the need of direct current for haulage equipment to permit the use of alternating current on all other electrical equipment, thus allowing operation of the mines with one system of power lines rather than two, as at present. The company specified that the locomotives must bear the approval of the Bureau of Mines before being placed in operation; if this company installs Diesel locomotives, delivery of one of them may be made during the latter part of 1945.

The adoption of Diesel locomotives for main-line haulage and use in conjunction with shuttle cars, various types of conveyors, or permissible storage-battery locomotives, for gathering and secondary haulage appears to present the best available means of eliminating the fire, ignition, and contact hazard of the thousands of feet of bare trolley and feeder wires found in mines using the trolley-locomotive system, now thought to total at least 50,000 miles in underground workings.

CONCLUSION

This paper is confined to discussion of the many hazards of the trolley-locomotive system, particularly those of the trolley wire, and gives typical examples of how this entire system has initiated gas or dust explosions, originated fires, and jeopardizes the life of workmen throughout its entire length by danger of contact. The system has so many inherent hazards that cannot be eliminated that despite its numerous operating advantages attention is called to the need of some far safer type of coal-mine haulage that would eventually displace a system using bare trolley wires for the source of power. In making this statement full cognizance is taken of the enormous capital investment of approximately 50,000 miles of underground trolley-haulage systems in the United States; nevertheless, it is a thought that should be considered carefully by those responsible for the safeguarding both mines and mine workers.

Regardless of the many hazards that were cited it cannot be expected that this system of haulage can or will be superseded by other systems in a short time, as both financial and commercial difficulties would almost prohibit a drastic change. Having knowledge of the many hazards and learning many lessons from previous disasters, explosions, and fires resulting from these known hazards, the mining industry can make the trolley-haulage system much safer by adopting corrective measures and following well known safety precautions.

The accidents discussed in this paper were classed in three groups: Contact of persons with wires or other electrical parts; gas or dust explosions; and fires, all from the trolley locomotive-haulage system. Relatively little discussion has been included after the description of these accidents or what precautionary measures might have prevented them, for it is believed that the only feasible method of prevention is the elimination of trolley wire in underground workings. However, some of the hazards apply to all three classes of accidents, while others are responsible for only one class. Although it is known that these hazards cannot be eliminated it is believed that the following suggestions will greatly minimize them.

Contact Hazards

The contact hazard could be greatly minimized by shielding every foot of the trolley wire, and certainly this should be done unless the bare trolley wire is at least 6-1/2 feet (preferably 7 feet) above the rail; this undoubtedly would be of value even though expensive, but the absence of guards is not entirely responsible for accidents, as factors of carelessness and neglect in observance of simple rules concerning installation and maintenance and use cause many accidents.

The trolley wire should be properly installed and located in relation to the track. Placing the trolley wire at least 6 inches outside of the rail, properly alined with sufficient hangers, not far apart, locating it on the side opposite the clearance side of haulage ways, and having adequate maintenance should aid greatly in decreasing the number of shock accidents.

Explosion Hazards

Explosions of gas and coal dust initiated by the numerous sparks and arcs given off by parts of the trolley-locomotive system have been discussed in some detail, the sparks or arcs resulting principally from the trolley wires, either by falling and making contact with other objects or by the contact of the trolley wheel or harp with the wire. Little can be done to prevent this sparking or arcing, and this hazard will always be present; however, the danger of explosions from this cause can be greatly reduced by operating the locomotive and extending the trolley wire in an air current which is adequate to reduce and carry off any liberated or accumulated firedamp.

Prevention of gas explosions is largely a question of adequate ventilation and the elimination of the source of ignition. The results of this are seen in the adoption of permissible machinery; there is no case on record of permissible equipment, maintained in a permissible condition, being the cause of an explosion. The trolley-haulage system cannot be made permissible, and the only way that it can be operated with any reasonable degree of safety and minimize the danger of explosions is in pure intake air.

The trolley locomotive should not be operated nor should the trolley wire be extended beyond any open crosscuts, into rooms, longwall faces, pillar workings or beyond continuously operating ventilating circuits effectively controlled by ventilating doors or stoppings. Curtains and loose gob stoppings or doors or stoppings that allow considerable leakage should not be considered effective.

Return airways or airways that receive air which has passed through old or abandoned workings should not be used as haulageways for trolley locomotives.

Where doors are needed to control the ventilation circuit they should be erected in pairs to form air locks, so that damage to one will not short-circuit or derange the ventilation.

"Nipping" or "stinging" the trolley wire when equipment is being moved should be prohibited.

Coal-dust explosions have been initiated by arcs or sparks from the trolley system, even when no gas has been present; likewise, the ignition of a small pocket of gas has caused widespread dust explosions. These can be greatly minimized by allaying the coal dust, and there is ample evidence of the effectiveness of rock dust in limiting explosions and of certain wetting methods in allaying dust.

The haulageways where the trolley locomotive travels should be adequately rock-dusted and the rock dust maintained so that a wrecked trip, or arcs from a fallen trolley, have little possibility of igniting the dust thrown into suspension. Water or a wetting agent should be used on all loaded trips; cars should be kept in repair to prevent leakage and should not be overloaded so that coal will fall or roll on the roadway and be ground into dust.

Fires

Fires caused by the trolley-locomotive system have been shown to be one of its greatest dangers. All of its numerous hazards may result in fires, and therefore this hazard is most difficult to control. Explosions can be reduced by adequate ventilation and precautions in using the locomotive, but a fire is possible along every foot of a trolley wire in a coal mine.

The following suggestions will not prevent fires but if followed will aid greatly in reducing the number and intensity of mine fires. Care should be exercised while installing trolley wires and bare feeder wires so they do not touch the roof, timbers, door frames, or other combustible material. When wires pass through door frames, a fire-resistant brattice cloth or other similar precaution should be used around doors.

Where curtains are used, provision should be made to prevent the brattice cloth of curtains from coming in contact with the trolley wire.

The trolley hangers should be suitably insulated and properly spaced, with enough hangers to prevent sagging; this is also a precaution against contact hazards.

The trolley line should be deenergized when not in use, and during idle and off-shift periods.

The trolley and feeder system should be sectionalized, with the section switches easily accessible and well-marked at intervals not exceeding 1,500 feet.

All rail joints should be bonded and crossbonded at regular intervals. Regular and periodical inspection should be made of bonds, and the bonding should be properly maintained.

Positive and sensitive automatic circuit breakers should be installed. Circuit breakers do not offer 100-percent protection against fires from all short circuits; but if properly set, adjusted, and maintained offer a fair degree of protection. They are not effective if set too high to overcome an overloaded circuit serving more equipment than for the load which the circuit breaker was designed. Many mining companies depend on circuit breakers but defeat their usefulness by setting the tripping release too high. The circuit breakers should be periodically inspected, cleaned, and tested to insure proper functioning.

The roof and timbering in haulageways should be inspected more frequently and better-maintained than at present to prevent the dislodgement of the trolley wire. The roadbed and track of haulageways and mine cars should be properly maintained to minimize the hazards of derailment with consequent knocking out timbers and bringing down the trolley wire.

Trolley haulage roads should be kept as nearly as possible free of loose, finely ground, combustible dust, and certainly road cleanings should not be piled against the rib along trolley haulage roads, as they supply a ready, quickly ignited fuel for the arc of a trolley wire and also allow quick spreading of any fire that gets started.

Trolley haulage roads should be sectionalized by placing doors along and in them in such manner that in case of fire in any part of a trolley haulage road the closing of one or possibly several doors would isolate and essentially seal the region in which the fire has occurred. At ordinary times these doors could be held open or closed in accordance with their effect upon ventilation.

A more detailed discussion of suggestions for improvements in the existing trolley-wire system for minimizing the hazards of arcs and sparks is contained in Information Circular 7302, Prevention of Fires Caused by Electric Arcs and Sparks from Trolley Wires, by F. E. Griffith, E. J. Gleim, R. T. Artz, and D. Harrington, issued in November 1944.